

Basic program optimizes core selection in transformer designs

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Most transformer designers agree that copper loss should equal core loss. Unfortunately, neither wire nor core material comes in continuous sizes. In most cases, a precise solution does not exist for any particular transformer, and designs are usually the result of a judgment call. An easy-to-use Basic program (found on EDN's BBS) can expedite the design procedure and allow you to exercise some discretion in selecting the core size.

In any transformer design, the principal parameters involved are source voltage, source frequency, load current, load voltage, and the core's operating flux level. In the article's design approach, the selected core's parameters are core area, window area, mean turn length, inductance constant, and fill factor.

You can usually establish two important limiting factors at the outset of any transformer design: the copper's current density and the core's flux density. The article focuses on the relationship between these two factors. Naturally, the current density in copper produces copper loss. Similarly, as a function of frequency, the flux density in the core produces core loss. If you plot the current density as a function of flux density, the results take the form of a hyperbolic curve (Fig 1).

Thanks to computers, the design task is relatively easy. You select a particular core size, then plot the current

A 503-line Basic program provides numerical and graphical information to aid you in selecting optimum core and wire types in transformer designs.

density in the copper against the core's flux density. The hyperbolic curve shifts because of the core size. The shift is principally a function of the effective core area and the window winding area. Thus, as you select smaller

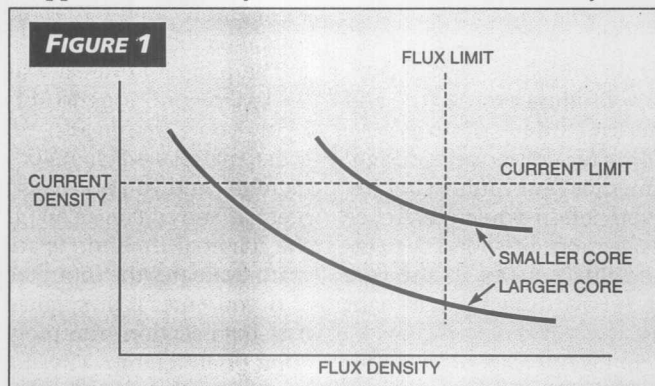
cores, the curve shifts closer to the limiting intersect point. Conversely, the curve moves away from the selected intersect point for larger core sizes. Once you make the selection, the Basic program optimizes the packaging efficiency and identifies the smallest suitable core size.

Fig 1 shows the relationship between the curves and the set of limits. Once you make the core selection, the program determines the appropriate wire gauge and the number of turns in the windings. Note: The routine loads and runs in Basic, GWBasic, and QBasic, with EGA and VGA graphics adapters. The routine *won't* run with a Hercules monochrome graphics adapter.

The PLOT routine in the program rapidly displays the relationship between the current density in the wire as a function of the flux density in the core. A typical upper value is

500 A/cm²; however, this value can change as a function of the applied heat-sink techniques. You can examine the relative limits of a particular core selection. For example, must you select a larger core, or can a smaller core provide a suitable safety margin?

In addition to speeding the core-selection process, the program allows you to compare designs using different core parameters. You can make comparisons for special designs by selecting whatever core area, winding



The relationship between current and flux density in a transformer takes the form of a hyperbolic curve. Once you choose current and flux limits, you should select the smallest core that keeps the curve safely within limits.



The Basic program described in this article is available on EDN's computer bulletin-board system (BBS). Phone (617) 558-4241 with modem settings 300/1200/-2400 8,N,1. Access //freeware SIG and specify (r)ead option followed by (k)eyword search for "MS800"

BASIC PROGRAM

area, or flux level you might want to use. This flexibility is useful when you require a special core size, and a suitable catalog core is not available.

You must review the loss levels for a particular core material, consider the frequency-induced skin effects in the windings, and determine the heat-dissipating capability of the packaging design. Once you've reviewed these considerations, the program provides a speedy answer to the sizing question.

The program's purpose is to assist in the core-size selection for a transformer; however, the program also helps in inductor design. For reasons explained later, the routine does not tabulate current density in the inductor but does tabulate the wire size to use and the number of turns. When you run the program, give all requested dimensional input data in centimeters. Wire sizes are usually in inches; however, the program lists the current density in both amps per square centimeters and amps per square inches. The program also gives wire sizes in AWG units. The program uses the following expressions and derivations Faraday's Law: $E = BNAf \cdot 10^8$, where E =rms voltage, B =flux density in gauss, N =number of turns, A =effective core area in square centimeters, f =frequency in hertz, and $k=4.44$ for a sine wave and 4 for a square wave.

$$AWG = 36 - \frac{39}{\log(92)} [\log(D) - \log(0.005)]$$

where D is the diameter of the wire in inches.

This expression for wire gauge uses the premise that 36-gauge wire has a 0.005-in. diameter, and 39 steps exist to the 0000-gauge wire, whose diameter is 0.46 in. You can calculate the diameter of the wire from the preceding expression

$$D = 0.005 \left(\frac{39}{\sqrt{92}} \right)^{36-AWG}$$

by solving for D :

These two expressions yield a complete wire table, which is one of the choices in the program's menu. The table gives diameter, area in circular mils, resistance per unit length, and other parameters for a given gauge. Note: Circular mils represents the size of a square hole through which the round wire fits, rather than the cross-sectional area of the wire. You can calculate inductance as $L = A_L N^2$, where A_L equals the inductance constant for the core (usually listed in the catalog, or you can assemble a known winding on the core and calculate the value), and N equals the number of turns.

The program gives three choices for component design: inductor, line-coupling transformer, or push-pull switching transformer. For all the choices, you obtain a quick-reference wire table. Only the transformer selections provide a current-density plot as a function of the flux density in the core because inductors and transformers have different dominant design parameters.

An inductor is essentially a voltage-dominated component. The principal design consideration for an inductor, aside from tuning and impedance concerns, is to ensure that it has enough turns to accommodate the circuit voltage without incurring core saturation. A transformer is primarily a load-dominated component. Of course, the windings must

DESIGN DATA FOR A COUPLING TRANSFORMER ?

OLD VALUE	NEW VALUE
Source frequency	0 ? 3000
Source Voltage	0 ? 110
Load Voltage	0 ? 440
Load Current	0 ? 0.1
Flux level in Gauss	0 ? 2000
Al in nH/T squared	0 ? 630
Winding Area	0 ? 0.77419
Core Area	0 ? 2.02
Mean Turn Length	0 ? 7.366
Fill Factor	0 ? 70

FIGURE 2

This Basic program requests input data in the NEW VALUE column. Once the program runs, the data shifts to the OLD VALUE column, and you can change any or all of the inputs for another run.

COUPLING TRANSFORMER	
THE SOURCE FREQUENCY IS	3000 HERTZ
THE SOURCE VOLTAGE IS	110 VOLTS
THE LOAD VOLTAGE IS	440 VOLTS
THE LOAD CURRENT IS	.1 AMPS
THE CORE FLUX DENSITY IS	2000 GAUSS
THE CORE INDUCTANCE CONSTANT IS	630 nH per turn squared
THE CORE WINDING AREA IS	.77419 cm squared
THE EFFECTIVE CORE AREA IS	2.02 cm squared
THE MEAN TURN LENGTH IS	7.366 cm
THE FILL FACTOR IS	70 %
THE TURNS RATIO IS	4
THE PRIMARY TURNS IS	204.4123 TURNS
THE SECONDARY TURNS IS	817.6494 TURNS
THE PRIMARY INDUCTANCE	2.632417E-02 HENRIES
THE PRIMARY WINDING	27 AWG
THE SECONDARY WINDING	33 AWG
THE PRIMARY CURRENT DENSITY	2527.359 AMPS per square inch
THE PRIMARY CURRENT DENSITY	391.7414 AMPS per square cm
THE SECONDARY CURRENT DENSITY	2540.091 AMPS per square inch
THE SECONDARY CURRENT DENSITY	393.7149 AMPS per square cm

(CR) for another run or MENU or PLOT for a graph ?

FIGURE 3

CORE.BAS provides the necessary parameters for a transformer design—turns ratio, primary and secondary turns, wire gauge, and the current densities in the primary and secondary.

have enough turns to accommodate the operating voltage, but the current density essentially depends on the load. The greater the load, the greater the current in the windings.

The three selections yield a tabulated list of the essential items for fabrication, including turns required and wire gauge. All the input data is tabulated on one screen for reference. You can use the computer's Print Screen key to print the tabulated data.

The program evaluates any type of core material because the basic expressions do not take core saturation into account. Thus, you can consider ferrite, metglas, silicon steel, and other materials. Below 4000 gauss, you typically use ferrite material, and you normally use other materials (for example, metglas and silicon steel) up to 20,000 gauss. You must know the material limitations and the operating levels. The program evaluates the input factors, regardless of the material.

If you enter a flux value greater than 4000 gauss in the core-data section, the program uses this level to select the appropriate x range. The flux value does not affect the y range for the current density. The set limit for current density is 500 A/cm². The limit values for flux are set at 3000 gauss for the 4000-gauss range and 15,000 gauss for the 20,000-gauss range. You can use limits that are commensurate with the requirements of a particular design.

BASIC PROGRAM

The following design example uses the coupling-transformer menu selection. The data-entry series for a switching transformer is the same, except that the source voltage is a dc voltage. The dc voltage is the voltage terminated at the center tap of the switching transformer. The switching-transformer program assumes the primary-voltage waveform is a square wave.

When you command the program to run, an introductory screen shows program version, date, and author information. Pressing the Enter key invokes the menu; you can return to the menu from a number of locations in the program. Select the coupling-transformer routine by pressing "2," then the Enter key. The program requests data entries; for the most part, you can obtain the required data from a core catalog. Remember that the required dimensional information is in centimeters and the inductance constant is in nanohenries per turn squared. Also, make sure your system is in DOS graphics mode.

The Basic routine requests input data in the following sequence: source frequency, source voltage, load voltage, load current, flux level in gauss, inductance constant is in nanohenries per turn squared, winding area, core area, mean turn length, fill factor in percentage.

As you enter new data for calculation, the old data remain for reference. If the inputs are correct, data are correct, then press the Enter key to make a calculation run. If the inputs are not correct, press N and re-enter the correct data after stepping down to the appropriate line. The calculation run computes and displays the original input data, followed by the transformer-winding information. The program makes rapid calculation runs following a change in any of the data entries.

Let's review the data-input sequence:

- **Source frequency:** An important selection; use a frequency lower (for example, 25% lower) than the transformer's operating frequency. You're operating on a curve, and a safety factor is always necessary. Let's assume an operating supply frequency of 4000 Hz; enter 3000 Hz.
- **Source voltage:** Judgment comes into play again. If the source impedance is low (for example, your wall socket), enter the source voltage. If you're matching one impedance to another, then you must take the reflected impedance into account to arrive at the correct input voltage. Let's assume 110V.
- **Load voltage:** Assume the load requires 440V.
- **Load current:** Assume the load requires 0.1A.
- **Flux level:** Assume you're using a ferrite core, and the operating flux will be 2000 gauss. (Note: This example uses a 3622 core from pgs 2 to 32 in the *Philips Components Catalog*, Eighth Edition.) However, the program works with any core material or configuration.
- **Inductance constant:** The selected 3622PA630 core has an A_L of 630 nH/(turns squared); enter 630.
- **Winding area:** The single-section bobbin for this core has a winding area of 0.12 in.², which converts to 0.77419 cm². Enter 0.77419.
- **Core area:** The effective core area is 2.02 cm²; enter 2.02.
- **Mean turn length:** The mean turn length is specified at 2.9 in., which converts to 7.366 cm; enter 7.366.
- **Fill factor:** This is another judgment call. It is not

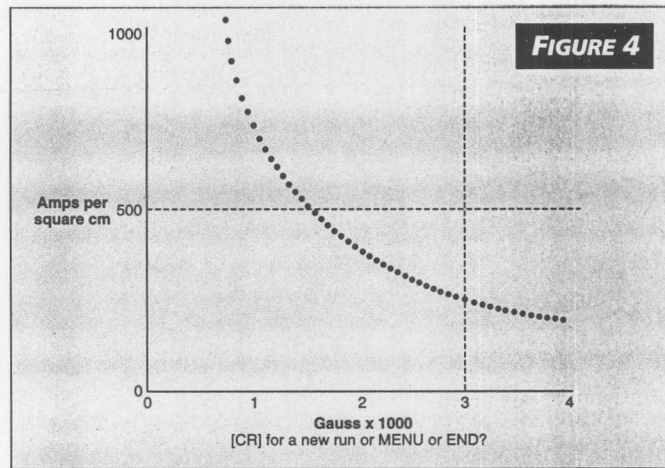


Fig 4—A hyperbolic curve describes the relationship between current and flux density in a transformer. After viewing this curve, you can go back and tinker with core selection, for a possibly smaller and more economical design.

likely that the winding area will be 100% filled, so enter 70 as a first try.

If the entered data is correct, then press the Enter key. If not, press N and alter the appropriate entry. The program lists the input data for reference and the calculated transformer winding parameters as follows: turns ratio, primary turns, secondary turns, primary inductance, primary winding wire gauge, secondary winding wire gauge, primary current density (per square inches and square centimeters), secondary current density (per square inches and square centimeters).

Fig 2 shows the screen that requests input data. After the program executes, the input data in the NEW VALUE column shifts to the OLD VALUE column. Fig 3 shows the format in which the program gives the calculated results. If you enter PLOT, you obtain a graph of current vs flux density, as shown in Fig 4. The first calculated result to look for is the current density. If the current density is over 500 A/cm², you must select a core with a larger winding area. If it's significantly less than 500 A/cm², you can choose a smaller core.

As a refinement, once you've obtained the plot, mentally draw a straight line from the current/flux level-intercept point to the origin and note the intersect point on the hyperbolic curve. Interpret the flux level at this point and rerun the program with this new flux level. You can do this in seconds; you then have a finished design that's ready for prototype fabrication and test.

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Author's biography

Gerald W West is an engineering consultant at PowerTech West, Seattle, where he has worked for eight years. He holds a degree in physics from the University of Washington, Seattle.

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